

****Volume Title****

*ASP Conference Series, Vol. **Volume Number***

****Author****

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SSOS: A Moving Object Image Search Tool for Asteroid Precovery at the CADC

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Abstract. While regular archive searches can find images at a fixed location, they cannot find images of moving targets such as asteroids. The Solar System Object Search (SSOS) at the Canadian Astronomy Data Centre allows users to search for images of moving objects. SSOS accepts as input either a list of observations, an object designation, a set of orbital elements, or a user-generated ephemeris for an object. It then searches for observations of that object over a range of dates. The user is then presented with a list of images containing that object from a variety of archives. Initially created to search the CFHT MegaCam archive, SSOS has been extended to other telescope archives including Gemini, Subaru/SuprimeCam, HST, and several ESO instruments for a total of 1.6 million images. The SSOS tool is located on the web at: <http://www.cadc.hia.nrc.gc.ca/ssos>

1. Introduction

In many fields of astronomy, image archives are of increasing importance. For example, since 2005, more than 50% of HST papers have been based on archival data rather than PI data. Archival images have become increasingly useful to extra-galactic and stellar astronomers in the last few years but, until now, solar system researchers have been at a disadvantage in this respect. While regular archive searches can find images at a fixed location, they cannot find images of moving targets.

This is unfortunate, because it could be argued that archival data is potentially more useful to solar system studies than extra-galactic or stellar astronomy. The full scientific potential derived from the discovery of small solar system bodies can not be fully realized until precise orbital parameters for those objects can be determined. Often, an object is detected but an orbit can not be determined until a significant amount of time has passed. If archival (precovery) images of the object exist, one can determine the orbital parameters immediately.

The Solar System Object Search (SSOS) at the Canadian Astronomy Data Centre (CADC) allows users to search for images of moving objects. The user enters either a set of observations, an object name, orbital elements or a full ephemeris. SSOS generates an ephemeris and returns a list of all matching images.

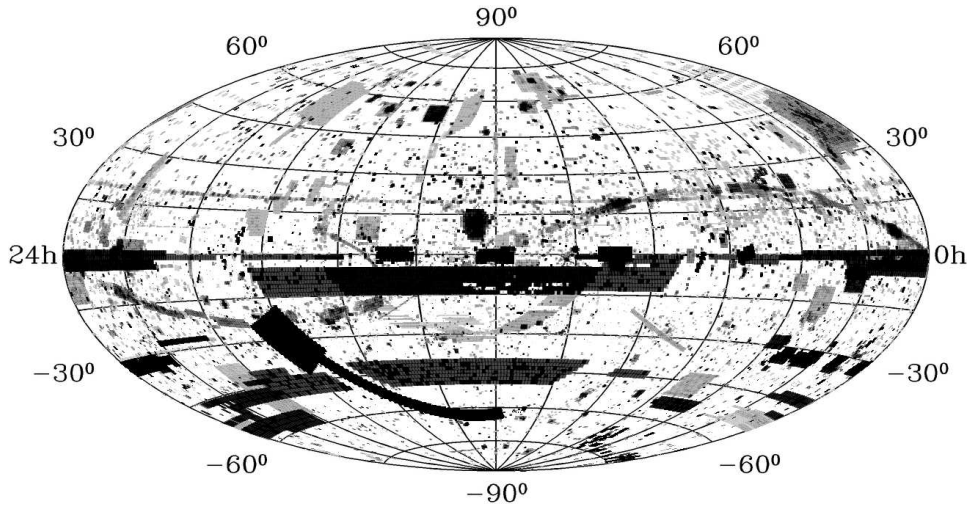


Figure 1. Area of the sky covered by SSOS. The greyscale gives an indication of the number of images covering a particular spot on the sky, with a single image being represented by the faintest grey, and 40 or more images being indicated by solid black.

2. Image Harvesting

Before any queries can be made, the SSOS image database must be populated. This is done by going to various telescope archives and harvesting the metadata describing each image taken by the telescope. For each image SSOS stores the following information: midpoint of exposure time, RA and Dec of the image center, and the extent of the image in RA and Dec. In addition, SSOS stores a bounding box in time, RA and Dec. The bounding box is in integer days (MJD) and integer degrees for RA and Dec.

Obtaining the metadata for images stored at the CADC, where SSOS is based, is relatively easy. The existing databases describing each image archive are queried directly and the relevant parameters are ingested into the SSOS database. To date, the archives of the following telescopes have been harvested from the CADC: CFHT (MegaCam and WIRCam), Gemini (GMOS), and HST (WFPC, ACS, and WFC3).

Offsite archives must be “scraped” over the web. This can take many forms depending on the archive. The Subaru SuprimeCam image lists are available as simple ASCII text files. The ESO archive can be queried repeatedly by date, eventually returning all the observations made by those telescopes. To date, the archives of the following telescopes have been harvested: AAT (WFI), ESO-LaSilla 2.2m (WFI), ESO-NTT (EFOSC, EMMI, SOFI, SUSI/SUSI2), ESO-VISTA (VIRCAM), VLT (FORs1, FORs2, HAWKI, NAOS-CONICA, ISAAC and VIMOS), and Subaru (SuprimeCam).

Currently, there are 1.6 million images in the SSOS database. Figure 1 shows the area of the sky covered by SSOS.

3. User Input and Conversion to Ephemeris

When arriving at the Solar System Object Search tool website, users have four ways to search for images. In each case, SSOS converts the user's input into an ephemeris. The four methods of input and conversion are detailed in the following four subsections:

3.1. Search by arc

In this input method, the user enters a series of observations in MPC format. SSOS then uses these observations to determine an orbit and generate an ephemeris from that orbit. The user can select one of two orbit fitting routines: The orbit fitting code of Bernstein & Khushalani (2000) has been set up to automatically convert the observations into orbital parameters (`fit_radec`) and use those parameters to produce an ephemeris (`predict`). SSOS also provides the new object ephemeris generator from the Minor Planet Center¹ as an alternative. If a user selects this option, the SSOS queries the MPC service automatically. The MPC fits a Väisälä orbit to the observations and returns an ephemeris based on this orbit. This method is slower than the Bernstein & Khushalani fitting because it requires SSOS to make queries to an external service. The ephemeris is generated at intervals of 24 hours. Mauna Kea (observatory code 568) is used as the observing site.

3.2. Search by object name

In this input method, the user enters the name of an object. SSOS then forwards that name to one of two services, either the Lowell Observatory asteroid ephemeris generator² or the minor planet and comet ephemeris service at the Minor Planet Center³. These services query their databases for an object matching the name, make the appropriate orbital calculations and return an ephemeris to SSOS.

In addition to using these two offsite services, SSOS can also generate an ephemeris locally. SSOS maintains a regularly updated copy of the MPC orbital element database⁴. When a user enters an object name, the local version of this database is queried and the orbital elements are passed to the program `orbfit` from the OrbFit software package (Milani & Gronchi 2010)⁵, which generates an ephemeris. As with the search by arc option, the ephemeris is generated at 24 hour intervals and Mauna Kea is used as the observing site.

3.3. Search by orbital elements

In this case, the user enters the orbital elements of an object: epoch, semi-major axis, eccentricity, inclination, longitude of the ascending node, argument of perihelion and mean anomaly. These orbital elements are used as input to the program `orbfit` which

¹<http://www.minorplanetcenter.net/iau/MPEph/NewObjEphems.html>

²<http://asteroid.lowell.edu/cgi-bin/asteph>

³<http://www.minorplanetcenter.net/iau/MPEph/MPEph.html>

⁴<http://www.minorplanetcenter.net/iau/MPCORB.html>

⁵<http://adams.dm.unipi.it/~orbmain/orbfit/>

returns an ephemeris, again at 24 hour intervals and using Mauna Kea as the observing location.

3.4. Search by ephemeris

This method allows the user complete control over the ephemeris. The user enters a series of times and object positions. Users can “cut and paste” text into the service. This method is useful if the user has any concerns about the positional accuracy of any of the previous methods. For example, the object in question might be near enough to the earth that the parallax will significantly affect the objects positions. Alternatively, the object’s apparent motion might be irregular enough that the linear daily interpolation scheme is insufficiently accurate.

4. Searching along the ephemeris

Once an ephemeris has been generated by one of the above methods, the next step is to match that ephemeris to the database of observations. The ephemeris can be thought of as a series of line segments in 3 dimensions: time, RA and Dec. SSOS builds an integer-valued bounding box (in both time and position) around each segment. The ephemeris is saved as a temporary table with both the integer bounding boxes and the exact (floating point) values. When the object moves across the first point of Aries, two rows are added, one each describing the position of the object on either side of the celestial meridian.

SSOS then matches this temporary table to its observation table. For speed, the integer bounding boxes are matched first. If a match is possible (*i.e.*, if the bounding boxes overlap) SSOS does a linear interpolation to determine the position of the object at the time of the exposure. A match occurs if this position is within the footprint of the image.

The key to keeping the queries reasonably fast are the integer bounding boxes and the linear interpolation. Doing a full orbital prediction for each of the images is not feasible. This is sufficiently accurate for the majority of queries, where the object either moves slowly or in a fairly straight line. A typical 20 year ephemeris can be matched to 1.6 million images in less than a second.

SSOS then returns a list of matching images to the user. Where possible, direct links to the images are provided; otherwise, SSOS provides links to pages where the images can be requested. On average, a search will return 20 images of a given asteroid, but this number can range from 0 (no hits) to several hundred.

References

- Bernstein, G. & Khushalani, B. 2000, AJ, 120, 3323
 Milani, A. & Gronchi, G. F. 2010, Theory of Orbital Determination (Cambridge University Press)